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Evaluating the surveillance for swine dysentery and progressive atrophic rhinitis in closed multiplier herds using scenario tree modelling

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Abstract

Background: The Swiss pig population enjoys a favourable health situation. To further promote this, the Pig Health Service (PHS) conducts a surveillance program in affiliated herds: closed multiplier herds with the highest PHS-health and hygiene status have to be free from swine dysentery and progressive atrophic rhinitis and are clinically examined four times a year, including laboratory testing. Besides, four batches of pigs per year are fattened together with pigs from other herds and checked for typical symptoms (monitored fattening groups (MF)).
While costly and laborious, little was known about the effectiveness of the surveillance to detect an infection in a herd. Therefore, the sensitivity of the surveillance for progressive atrophic rhinitis and swine dysentery at herd level was assessed using scenario tree modelling, a method well established at national level. Furthermore, its costs and the time until an infection would be detected were estimated, with the final aim of yielding suggestions how to optimize surveillance.

Results: For swine dysentery, the median annual surveillance sensitivity was 96.7 %, mean time to detection 4.4 months, and total annual costs 1022.20 Euro/herd. The median component sensitivity of active sampling was between 62.5 and 77.0 %, that of a MF between 7.2 and 12.7 %.
For progressive atrophic rhinitis, the median surveillance sensitivity was 99.4 %, mean time to detection 3.1 months and total annual costs 842.20 Euro. The median component sensitivity of active sampling was 81.7 %, that of a MF between 19.4 and 38.6 %.

Conclusions: Results indicate that total sensitivity for both diseases is high, while time to detection could be a risk in herds with frequent pig trade. From all components, active sampling had the highest contribution to the surveillance sensitivity, whereas that of MF was very low. To increase efficiency, active sampling should be intensified (more animals sampled) and MF abandoned. This would significantly improve sensitivity and time to detection at comparable or lower costs.
The method of scenario tree modelling proved useful to assess the efficiency of surveillance at herd level. Its versatility allows adjustment to all kinds of surveillance scenarios to optimize sensitivity, time to detection and/or costs.

Keywords: Breeding herds, Freedom from disease, *Brachyspira hyodysenteriae*, Toxigenic *Pasteurella multocida*, Disease detection, Surveillance sensitivity, Sampling, Cost-efficiency

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Background

The Swiss pig population enjoys a generally favourable health situation [1]. Apart from freedom from porcine reproductive and respiratory syndrome virus and officially OIE listed diseases, clinical appearance of enzootic pneumonia, porcine actinobacillosis and progressive atrophic rhinitis has been eliminated [2]. To further promote this good health status, the Pig Health Service (PHS), conducts a surveillance programme for various economically relevant diseases in affiliated herds (2′249 or 85 % of all breeding herds and 1′380 or 50 % of all fattening herds in Switzerland in 2013 [3, 4]). All herds are assigned to different categories, depending on their production stage, health and biosecurity status. Herds in the highest PHS-category (136 herds with a median of 83 sows per herd, ranging from 28 to 400 sows, in 2013) comprise closed multiplier herds (61 herds), multiplier herds with outsourced rearing of breeding gilts (38 herds) and the herds where these gilts are reared (37 herds). These herds have to comply with strict hygiene and biosecurity requirements (e.g. no purchase of animals from other herds, other than by embryo-transfer or hysterotomy). They must provide consistent evidence that they are free from progressive atrophic rhinitis (PAR), swine dysentery (SD), sarcoptic mange and lice. Whereas for the last two there is no active surveillance in place, the first two diseases (PAR and SD) are monitored for with an intensive surveillance scheme as laid down in the PHS technical guideline [5].

Swine dysentery is caused by the bacterium *Brachyspira (B.) hyodysenteriae,* and manifests itself in severe mucohemorrhagic diarrhoea. It generates tremendous financial loss not only due to acute mortality in affected pigs, but also decreased growth rate, poor feed conversion and expenses for chemotherapy [6]. Toxigenic *Pasteurella (P.) multocida* is the causative agent of PAR, which is characterized by progressive deformation up to complete disappearance of the nasal turbinates, accompanied by facial distortion, in infected pigs. The disease, while not causing significant losses among animals, still has a detrimental economic impact on affected farms due to severe growth retardation and poor fattening performance in affected juvenile pigs [7].

The closed multiplier herds of the highest PHS-category are examined by PHS-or associated veterinarians four times a year. Each visit includes sampling of animals for laboratory examination for either SD or PAR (so that each disease is tested for twice a year). Furthermore, four so-called monitored fattening groups with pigs from different origins (MF) are arranged per multiplier herd and year. This method is quite specific to Switzerland and has been widely used, e.g. in the nationwide clinical elimination campaign for enzootic pneumonia [2]. Herein, at the beginning of a fattening period, piglets from the herd to be monitored are commingled with piglets from other (naïve) herds following a predefined protocol. Pigs are then checked for arising clinical signs in the course of the fattening period by PHS-veterinarians, and during post-mortem inspection at the slaughterhouse.

While clearly being labour- and cost-intensive, little was known about the sensitivity of the surveillance. Although the number of samples to be taken was increased after a PAR outbreak in a closed multiplier herd and several contact herds in 2011 [8], general questions arose about the system's actual effectiveness to (timely) detect an infection in a herd that would justify the high efforts.

Therefore, the rationale for this study was to gain knowledge of the efficiency of the current PAR and SD surveillance in closed multiplier herds, using scenario tree modelling (STM). This methodology, a now well-established method to model and assess the sensitivity of surveillance systems, was first introduced by Martin et al. [9]. They stated that contrary to other approaches like qualitative assessments via expert panels or structured representative surveys of the population, STM combines the objective quantitative analysis of different complex data sources to support evidence of freedom from disease. This is done creating stochastic scenario tree models for each component of a surveillance system and estimating their sensitivity. All resulting component sensitivities are then combined into one estimate of the overall sensitivity of the surveillance system. In Switzerland, the method was already applied to estimate the value of targeted herd sampling to substantiate freedom from enzootic bovine leucosis and infectious bovine rhinotracheitis [10], to establish a national surveillance system for bluetongue disease [11] or assess national surveillance of bovine tuberculosis [12]. As also shown in the given examples, to date, the methodology has been used to assess probability of freedom from disease and surveillance at regional or national level [13–15]. In the present study it shall be applied to assess surveillance at herd level. The first aim of this study was thus to assess and compare the sensitivities of different surveillance components as well the overall surveillance sensitivity. As a second aim, the average time to detection of an infection in a herd should be estimated. Since in practice decisions on the most suitable surveillance system cannot exclusively be driven by technical aspects but must also account for financial considerations, the costs incurring to the PHS for each surveillance component and for the surveillance as a whole per farm and year were calculated. The additional modelling of different alternative surveillance scenarios, thus providing suggestions for an optimized surveillance in terms of an improved sensitivity, time to detection or cost-efficiency, was the last aim of this study.

Methods

Data collection

First, a literature search was conducted to obtain quantitative data to be used in the in the scenario tree models. Since no sufficient information could be found on several of the parameters, an expert elicitation was done among Swiss pig veterinarians. A questionnaire was set up using the SurveyMonkey® online-tool (SurveyMonkey, Palo Alto, USA) and sent out via e-mail to all veterinarians employed by or associated to the PHS (i.e. private practitioners that carry out farm visits for the PHS on a regular basis), including all veterinarians with a nationally certified specialization in pig medicine or diploma of the European College of Porcine Health Management (ECPHM), as well as the institutes' leaders of the swine clinics of the Vetsuisse Faculty Berne and Zürich. Since not all herds in Switzerland are free from PAR or SD, it was assumed that these veterinarians had expert knowledge on the frequency and clinical manifestation of these diseases in the country. The questionnaire comprised questions about the estimated prevalences of SD and PAR in infected herds, the likelihood of clinical signs in infected herds or the probability that a farmer would detect an infection in his herd or in a monitored fattening group (full questionnaire can be obtained upon request from the first author). For each parameter in question, experts were asked to estimate the most likely value, the minimum and the maximum value. In total, 45 out of 127 experts (36 %) completed the questionnaire. From all answers, the median over all experts' estimates was calculated for the most likely, the minimum and the maximum value for each parameter separately. The data/results that were obtained from these different sources and that were used in the scenario tree models are presented in Table 1.

Construction of the scenario tree models

In a scenario tree model, the pathway including all steps necessary to lead to a certain event (here: detection of an infection in a herd) is plotted. A value (usually a probability) is then assigned to each step within the tree, and finally all values are combined to obtain the overall sensitivity, i.e. probability to detect an infection.

Such scenario trees were created in Excel 2010® software (Microsoft Corporation, Redmont, USA) for all surveillance components currently conducted in closed multiplier herds over the course of one year for PAR and SD surveillance, respectively, as follows:

1. Clinical surveillance by the farmer

This comprised the every day's surveillance of the pigs by the farmer. The corresponding scenario tree

Table 1 Model parameters including their values/distributions and sources of information

Parameter	Description	Values (min.; most likely; max.)		Source	
		SD	PAR	SD	PAR
CS	Probability of clinical signs in one or more animals in an infected closed multiplier herd	0.01;0.2;0.5	0.1;0.2;0.4	expert poll	[8], expert poll
FcV	Probability that a closed multiplier farmer informs vet./PHS about clinical signs	0.5;0.75; 0.9	0.45;0.7; 0.9	expert poll	
VcS	Probability that veterinarian takes samples for laboratory examination	0.5;0.9;1		expert poll	
Intrapr	Intra-herd prevalence (herd with clinical signs)	0.3;0.6;0.9	0.05;0.15;0.4	expert poll	[8]
Intraprnoc	Intra-herd prevalence (no clinical signs)	0.1;0.25;0.5	-	expert poll	[8]
TsensPCR	Probability that test classifies a true positive sample as positive (PCR after culture)	0.62;0.73;0.83	0.85;0.85;1	[16]	[17]
TspecPCR	Probability that test classifies a true negative sample as negative (PCR after culture)	0.91;0.97;1	0.98;0.99;1	[16]	pers. comm. G. Schüpbach
CSMF	Probability that pigs show clinical signs during MF with infected animals	0.05;0.125;0.4	0.2;0.5;0.7	expert poll	
MFFiV	Probability that MF farmer informs PHS about signs	0.27;0.6;0.75	0.3;0.5;0.78	expert poll	
AnAS	Number of animals sampled via active sampling (per visit)	4 / 6 (4;10)*	10 (4;10)*	[5]	
NAS	Number of visits with active sampling	2 (2;4)*		[5]	
NCLINPHS	Number of visits with clinical examination	2 (2;4)*		[5]	
NMF	Number of MF with telephone check	3 (1;4)*		[5]	
NMFPHS	Number of MF with on-farm examination	1 (1;4)*		[5]	
AnSUS	Number of animals sampled in the case of suspicion	20 (10;25)*		[5]	

(SD = swine dysentery; PAR = progressive atrophic rhinitis; MF = monitored fattening group; * = parameters with fixed values in the regular model and with uniform distributions (ranges indicated in brackets) for sensitivity analysis only)

(the general process is identical for PAR and SD) is depicted in Fig. 1. If any of the animals showed symptoms indicative of one of the two diseases and the farmer detected them, he/she should inform the PHS who then sent a veterinarian for further investigation of the suspicion and, if the clinical suspicion was acknowledged, for laboratory confirmation.

In the case of SD, the main observable clinical sign was mucous or even bloody diarrhoea. Upon suspicion of SD, fecal swabs from 20 animals (two animals were pooled in one swab, thus yielding ten pooled samples) were to be taken according to the PHS technical guideline [5]/(Table 1) and sent to the to the Institute of Veterinary Bacteriology, Vetsuisse Faculty, University of Zurich, Switzerland, for cultural examination for *Brachyspira* spp. followed by species identification via polymerase chain reaction (PCR) in the case of positive cultures.

In the case of PAR, clinical signs included sneezing, nose bleeding or nose deformities. Upon suspicion of PAR, nasal swabs from 20 animals (equalling ten pooled samples) were to be taken and sent to the same laboratory. The examination protocol included overnight incubation of samples at 37° on *Pasteurella* agar containing bacitracin and neomycin and examination of colony material in *tox*A-PCR [17].

The probability that at least one of these animals yielded a positive result (i.e. the herd-level sensitivity of the test *HSe*) was calculated using the formula:

$$HSe = 1\text{-}\left(1\text{-}(Intrapr * TsensPCR + (1\text{-}Intrapr) * (1\text{-}TspecPCR)\right)^{20} \quad (1)$$

This means, the herd-level sensitivity depended on the intra-herd prevalence, the test sensitivity and specificity and the number of animals sampled. The total component sensitivity of clinical surveillance by the farmer (*SComSeCLIN*) was then:

$$SComSeCLIN = CS * FcV * VcS * HSe \quad (2)$$

This means, the sensitivity of clinical surveillance depended on the probabilities of clinical signs, that a farmer informs a veterinarian about symptoms, that a veterinarian conducts sampling and the herd-level sensitivity. Since it could not be predicted if and how many times during a year this event can happen, it was accounted for once in the total surveillance sensitivity.

2. Clinical surveillance by the PHS

Four farm visits by the PHS were mandatory for each closed multiplier herd in the highest PHS-category in every year. For both diseases active sampling was required twice a year, therefore, in practice, on one visit samples were taken for one disease, whereas on the following visit the other disease was sampled for, and so on. This means that for each disease two visits relied on clinical examination and samples were be taken only if the PHS veterinarian noticed suspicious symptoms in the herd. In that case she/he was to take the same samples as indicated under 1. clinical surveillance by the farmer, resulting in the same *HSe* as described in equation 1. The respective tree is shown in Fig. 2. The

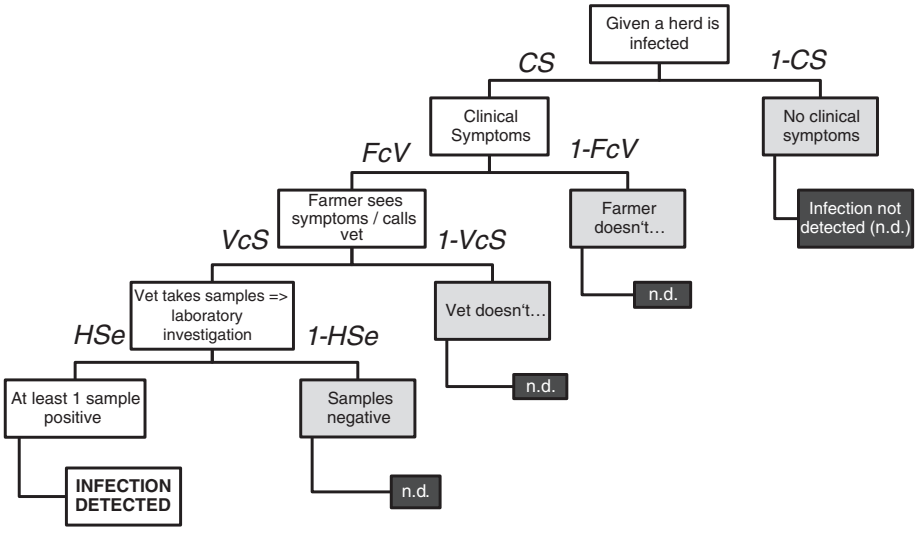

Fig. 1 Scenario tree of the clinical surveillance by the pig farmer. Scenario tree to describe the pathway necessary to detect an infection via clinical surveillance by the farmer (*SComSeCLIN*), (*CS* = probability (p.) of clinical symptoms, *FcV* = p. that farmer calls veterinarian, *VcS* = p. that veterinarian conducts sampling, *HSe* = herd sensitivity)

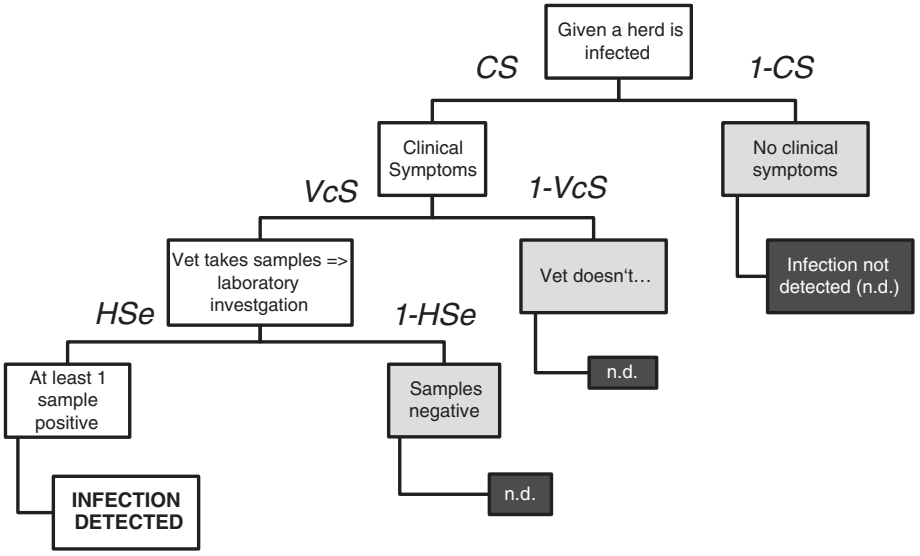

Fig. 2 Scenario tree for clinical surveillance by PHS. Scenario tree to describe the pathway necessary to detect an infection via clinical surveillance by the pig health service (*SComSeCLINPHS*), (*CS* = probability (p.) of clinical symptoms, *VcS* = p. that veterinarian conducts sampling, *HSe* = herd sensitivity)

component sensitivity of clinical surveillance by the PHS (*SComSeCLINPHS*) was then:

$$SComSeCLINPHS = CS * VcS * HSe \quad (3)$$

In other words, the sensitivity of clinical surveillance by the PHS depended on the probabilities of clinical signs, that a veterinarian conducts sampling and the herd-level sensitivity. Because the event happened twice a year (Table 1), it was accounted for twice in the calculation of the total annual surveillance sensitivity for each disease.

3. Active sampling by the PHS

As described above, active sampling was done twice a year for each disease in each herd (following the same laboratory examination protocols as described under 1.). For SD, on one visit faecal swabs from four animals were taken (pooled into two samples), on the other visit faecal swabs from six pigs (three pooled samples) were tested for the presence of *B. hyodysenteriae* (i.e., in total ten animals/five pooled samples were tested each year). For PAR, nasal swabs from twice ten pigs (twice five pooled samples) were taken and examined for toxigenic *P. multocida* (so in total, 20 animals or ten pooled samples were examined each year). The total component sensitivity for PAR was—apart from the different number of animals sampled—identical to the formula for the *HSe* described under 1. (equation 1); in the case of SD with the modification of using *Intraprnoc* instead of *Intrapr* for the intra-herd prevalence, since the intra-herd prevalence of SD in clinically unaffected herds was assumed to be lower than in clinically suspicious herds.

$$SComSeAS = 1-(1-(Intraprnoc*TsensPCR+(1-Intraprnoc)*(1-TspecPCR)))^{no.\ of\ animals\ sampled} \quad (4)$$

This means, the sensitivity of active sampling depended on the intra-herd prevalence (SD: if no clinical signs present), the test sensitivity and specificity and the number of animals sampled. The event was also accounted for twice in the calculation of the total annual surveillance sensitivity for each disease (Table 1).

4. Monitored fattening groups

Every year four MF were conducted per herd, where fattening pigs from the monitored herd were commingled with fattening pigs from another, naïve herd. One of these MF was checked by a visiting PHS veterinarian. The other three were just checked telephonically, i.e. at the end of the fattening period the farmer conducting the MF receiveed a phone call by the PHS and was asked whether he/she had observed any suspicious symptoms in the pigs or if there had been a need for any medical treatment. In case the farmer indicated or the PHS veterinarian perceived suspicious symptoms, again 20 animals were sampled for laboratory examination.

The tree for the latter situation is shown in Fig. 3. The component sensitivity was then:

$$SComSeMF = CSMF * MFFiV * VcS * HSe \quad (5)$$

This means, the sensitivity of MF depended on the probabilities of clinical signs during MF, that a farmer informs a veterinarian about symptoms, that a veterinarian conducts sampling and the herd-level sensitivity.

This event was accounted for three times in the calculation of the total annual surveillance sensitivity for each disease (Table 1). For the one MF where the check was done by the PHS veterinarian himself/herself, the same tree and formula applied, just omitting the step *MFFiV*; the resulting component sensitivity was then called *SComSeMFPHS*.

Calculating the total surveillance sensitivity

For each disease separately, the total annual herd level sensitivity, i.e. ability to detect an infection in a herd over one year, was calculated combining the different component sensitivities. The equation for SD was:

$$\begin{aligned} ToSe_{SD} = {} & 1-(1-SComSeCLIN) * \left(1-SComSeCLINPHS^2\right) \\ & *(1-SComSeAS_{6animals}) * (1- SComSeAS_{4animals}) \\ & *\left(1-SComSeMF^3\right) * (1-SComSeMFPHS) \end{aligned} \quad (6)$$

In other words, the total sensitivity of the SD surveillance was obtained combining the sensitivities of clinical surveillance by the farmer and twice the PHS, the sensitivities of twice active sampling, and the sensitivities of surveillance via MF (once by the PHS, three times by the farmer). The same applied for PAR, where the total sensitivity was calculated as follows:

$$\begin{aligned} ToSe_{PAR} = {} & 1-(1-SComSeCLIN) * \left(1-SComSeCLINPHS^2\right) \\ & *\left(1-SComSeAS^2\right) * \left(1-SComSeMF^3\right) \\ & *(1-SComSeMFPHS) \end{aligned} \quad (7)$$

To account for uncertainty and variability in the data, a stochastic approach was followed, such that model parameters were distributed instead of incorporating fixed values. Pert distributions which are most suitable for data obtained from expert opinion were used. These are defined by a most likely, a minimum and a maximum value (see Table 1). To obtain the overall results, 50.000 iterations were run in @risk® software (@risk 5.7, Palisade Corporation, Ithaca, USA).

Sensitivity analysis

A so called sensitivity analysis is a formal tool used in modelling processes to assess the relative impact of each model parameter on the overall outcome (in this context *sensitivity* relates to the sensitivity of an outcome to changes of an input parameter and should not be confused with the terms *component* / *surveillance sensitivity* denoting the model outcomes of this study). This was

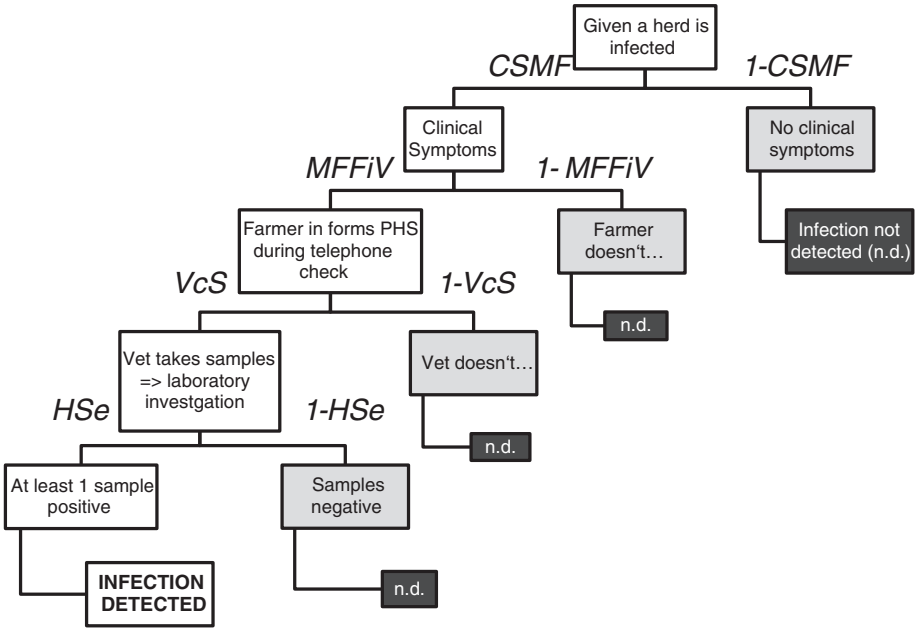

Fig. 3 Scenario tree for the surveillance in MF with telephone check by the PHS. Scenario tree to describe the pathway necessary to detect an infection via surveillance in MF by telephone check by the Pig Health service (*SComSeMF*), (*CSMF* = probability (p.) of clinical symptoms in MF, *MFFiV* = p. that farmer conducting MF informs veterinarian, *VcS* = p. that veterinarian conducts sampling, *HSe* = herd sensitivity)

done creating tornado graphs in @risk, in which the change in the total surveillance sensitivity is assessed when the value for a distributed input parameter is changed from its 1st to its 99th percentile. The length of the bar of each parameter then indicates the relative magnitude of its impact. Since tornado graphs can only be created for distributed variables, uniform distributions were inserted for the originally fixed variables to gain knowledge about their relative importance as well. Likely ranges for these distributions were defined according suggestions by the PHS and are given in Table 1.

Time to detection of infection

The total surveillance sensitivity indicates the sensitivity of a surveillance system over one year, but it does not tell us how rapidly an infection would be detected. Since the time from an infection to its detection in a herd can be pivotal for the further course and control of an outbreak, it should be another very important criterion in the evaluation of a surveillance system. Therefore, the average time between infection of a herd and its detection was also estimated:

$$TD = SComSe_1 * 0.5I + (1\text{-}SComSe_1) * SComSe_2 * 1.5I + (1\text{-}SComSe_1) * (1\text{-}SComSe_2) * SComSe_3 * 2.5I \ldots (and\ so\ on) \quad (8)$$

Herein, *TD* was the time to detection in months; *SComSe* was any surveillance component sensitivity; *I* was the average time interval in months between surveillance components.

All component sensitivities were incorporated using their median value. For simplicity it was assumed that all components were distributed equally over a period of 12 months. This means that in the current surveillance with totally 6 different surveillance components per year (1x *SComSeCLIN*; 2x *SComSeCLINPHS;* 2x *SComSeAS*; 1x *SComSeMFPHS;* 1x $SComSeMF^3$, because in practice mostly only one phone call was done after three MF to cover all three of them*; SComSeCLIN* was not accounted for in this calculation), the average time interval between different events was 2 months.

For each disease, a best case and a worst case scenario were considered. In the best case scenario, by chance the surveillance component with the highest sensitivity took place first after the introduction of an infection, then the second most sensitive surveillance component etc. In the worst case scenario it was assumed that by chance the surveillance component with the lowest sensitivity was conducted first after the infection, then the surveillance component with the second lowest sensitivity, and so on. Notwithstanding the foregoing, it was made sure in the chronological order that a visit with active sampling was not directly followed by another visit with active sampling etc., but that visits with and without sampling would alternate.

Costs of the surveillance

To calculate costs of the surveillance for the PHS, costs for laboratory examinations were retrieved from the laboratory in charge; for labour and travel costs an average was calculated based on PHS salary schemes, the time spent for the examination and an average travel distance to a farm.

Total costs of a surveillance component, indicated in Table 2, comprised those incurring at any case (regular costs) as well as those incurring only upon suspicion (e.g. in clinical surveillance by the farmer there were no regular costs; in clinical surveillance by the PHS and of MF, travel and labour costs incurred regularly, whereas costs related to sampling and laboratory investigation incurred only upon suspicion, etc.). The costs upon suspicion were multiplied with the probability that a herd would experience a suspicion and that further actions were taken. This probability was obtained from PHS records from the past two years: for each disease separately, the annual number of herds investigated due to suspicion was counted and related to the total number of herds. This resulted in an average of 5 % for both PAR and SD. Costs were calculated in Swiss Francs (CHF) which herein was regarded as equivalent to Euro (EUR) due to quasi-exchange parity of the two currencies around the time of publication (07.05.2015: 1.037 CHF = 1 EUR). Therefore it was abstained from calculating an extra exact value in EUR since the difference to CHF would have been marginal.

Table 2 Types of costs and values used for the calculation of the overall costs of surveillance

Type of costs	Costs in CHF (≈ EUR)
Labour costs for PHS vets per visit (visit on average one hour, salary veterinarian 55 CHF/h)	Ø 55.00
Travel costs to farm, per visit (0.67 CHF / km, on average 60 km)	Ø 40.00
Express delivery of samples to laboratory, per visit	16.00
Laboratory examination, per sample	60.00 (SD) / 20.00 (PAR)
Examination of MF at slaughterhouse, per batch	15.00
Phone calls to check MF, labour costs per call (call on average 15 min., salary of secretary 30 CHF/h)	Ø 7.50

Costs are indicated in Swiss Francs (CHF) as equivalent to Euro (EUR). (No extra value in EUR given due to marginal difference to CHF at the time of publication (07.05.2015: 1.037 CHF = 1 EUR); SD = swine dysentery; PAR = progressive atrophic rhinitis; MF = monitored fattening group)

Alternative scenarios

To compare different other surveillance options and elaborate suggestions for a potential optimization of the current surveillance, different alternative scenarios were calculated. These were:

- omitting surveillance via MF (no *SComSeMF* and *SComSeMFPHS),*
- omitting active sampling (this option was rather included for reasons of comparison since this is how multiplier herds with outsourced rearing of breeding gilts are currently monitored)
- omitting surveillance via MF and increasing the number of active samples (i.e. animals) per visit to 10 (SD) and 16 (PAR)
- omitting surveillance via MF and increasing the number of visits with active sampling per year to 4, while each time sampling 6 animals (SD and PAR)

Results

Swine dysentery (SD)

The sensitivity of the surveillance system, i.e. the probability that an infection in a closed multiplier herd is detected within one year, is given in Table 3. A sensitivity tornado revealed that for SD the intra-herd prevalence, if no clinical signs were present, had the highest relative impact on the total sensitivity of surveillance, followed by the number of animals sampled during active sampling and the number of active samplings per year (for the tornado graph, see Additional file 1).

The time to detection for SD was 2.3 months in the best case and 6.4 months in the worst case with a mean of 4.4 months. Total costs for the SD surveillance were 1022.20 CHF (≈ EUR) per herd and year (Table 3) summing up to a total of 62′354.20 CHF (≈ EUR) for all 61 closed multiplier herd per year.

The results of different alternative scenarios with their surveillance sensitivity, time to detection and costs are listed in Table 4.

Table 3 Component sensitivities, total annual surveillance sensitivity and costs of the SD surveillance system

SD surveillance component sensitivities for:	Sensitivity %			Costs CHF (≈ EUR)
	5%ile	Median	95%ile	
- Clinical Surveillance by farmer (*SComSeCLIN*)	4.5	13.1	24.5	35.55
- Clinical Surveillance by PHS (*SComSeCLINPHS)*	6.3	18.0	32.7	220.80
- Active sampling of 6 animals (*SComSeAS*)	58.3	77.0	89.6	291.00
- Active sampling of 4 animals (*SComSeAS*)	44.2	62.5	77.8	231.00
- MF, examination by PHS (*SComSeMF*)	6.0	12.7	23.6	140.80
- MF, telephone check (*SComSeMFPHS*)	3.2	7.2	14.0	103.05
Total annual surveillance sensitivity ($ToSe_{SD}$)	89.8	96.7	99.2	1022.20

For monitored fattening groups (MF) (SComSeMFPHS), the component sensitivity is given for one MF whereas costs are summed up over all MFin one year. ((No extra value in EUR given due to marginal difference to CHF at the time of publication (07.05.2015: 1.037 CHF = 1 EUR); SD = swine dysentery)

Progressive atrophic rhinitis (PAR)

The component sensitivities and total annual sensitivity of PAR surveillance are given in Table 5. The sensitivity tornado (for the graph, see Additional file 2) indicated that after the intra-herd prevalence, the second and third most important parameters were the number of animals sampled during active sampling and the probability that a veterinarian takes samples in case of clinical suspicion.

For PAR, the TD was between 1.8 and 4.4 months (mean 3.1 months) with total annual costs of 842.20 CHF (≈ EUR) per herd (Table 5) and 51′374.20 CHF (≈ EUR) for all 61 closed multiplier herd per year. The resulting surveillance sensitivity, time to detection and costs of different alternative scenarios are listed in Table 4.

Discussion

Switzerland is a country with a high health-status in its pig population, especially in pig health service-affiliated herds. To maintain it, a systematic and efficient surveillance is mandatory. This study aimed at the evaluation of the current surveillance by the PHS for swine dysentery and progressive atrophic rhinitis – i.e. the overall annual sensitivity to detect an infected herd, the time to detection and total costs for the PHS– in Swiss pig multiplier herds of the highest PHS-hygiene status. The overall annual sensitivity to detect an infected herd was found to be high for both diseases, with a median of 99.4 % for PAR and 96.7 % for SD. These satisfactory results come at quite high costs though, with 842.20 CHF (≈ EUR) per herd and year for PAR and even higher costs of 1022.20 CHF (≈ EUR) for SD.

The biggest contribution to the overall sensitivity had in both cases active sampling with the highest component sensitivities of all surveillance components. The value itself was slightly lower for SD than for PAR, on one hand due to the lower sensitivity of the laboratory test for detection of *B. hyodysenteriae*, on the other hand due to the very low number of animals examined (four and six pigs per visit, respectively) because of the high costs for the test. This number of animals examined had a high relative impact on the overall result, especially in connection with the rather low assumed intra-herd prevalence (*Intrapr* for PAR / *Intraprnoc* for SD). These were the parameters with the highest relative importance

Table 4 Surveillance sensitivity, time to detection and costs for alternative surveillance scenarios for SD and PAR

	ToSe		TD (months)			Costs per farm and year CHF (≈ EUR)
	Median	90 % CI	best case	worst case	mean	
SD						
Current surveillance (for comparison)	*96.7*	*89.8–99.2*	*2.3*	*6.4*	*4.4*	*1022.20*
No MF	95.1	85.4–98.8	3.3	6.1	4.7	778.35
No AS	60.5	33.5–78.8	11.6	13	12.3	500.20
2x10 samples no MF	99.6	96.7–99.97	2	4.4	3.2	1078.35
4x6 samples no MF	99.8	97.4–99.99	2.4	2.4	2.4	1199.55
PAR						
Current surveillance (for comparison)	*99.4*	*95.1–99.9*	*1.8*	*4.4*	*3.1*	*842.20*
No MF	98.0	87.7–99.9	2.7	5	3.85	638.35
No AS	80.9	65.4–91.2	6.9	8.6	7.75	420.20
2x16 samples no MF	99.7	95.5–100.0	1.9	4.3	3.1	758.35
4x6 samples no MF	98.5	88.0–99.9	3.2	3.2	3.2	699.55

(SD = swine dysentery; PAR = progressive atrophic rhinitis; ToSe = total surveillance sensitivity; CI = confidence interval; MF = monitored fattening group; AS = active sampling; ToSe = total sensitivity; TD = time to detection; no extra value in EUR given due to marginal difference to CHF at the time of publication (07.05.2015: 1.037 CHF = 1 EUR))

according to the sensitivity tornados, since they determine the likelihood that the – especially in the case of SD—low number of samples taken during active sampling is enough to detect the infection. While being the most effective component, active sampling also constituted the biggest proportion of the overall costs for both surveillance programmes.

Component sensitivities of monitored fattening groups were found to be rather low. While still acceptable in the case of PAR and examination by the PHS veterinarian (median of 38.6 %), the sensitivity for SD was low in the case of an examination by the PHS veterinarian (12.7 %) and even lower if the MF was checked telephonically only. Firstly it is not deemed an optimal solution to base the surveillance on the farmer only, as it is done in the three telephone-checked MF, even more so considering the rather low disease awareness of these farmers to recognize and notify these symptoms to a veterinarian. Furthermore, this can be attributed to the fact that the probability of apparent clinical signs during MF was estimated to be low especially for SD. This is not astonishing since MF were established predominantly for the surveillance of enzootic pneumonia (EP) with coughing as an easy assessable symptom, and other diseases like sarcoptic mange with pruritus as another easy recognizable symptom. In these cases, MF were a well suitable means, and significantly contributed to a successful control of EP in Switzerland [2]. For the present diseases though, it gave way to the question if the small gain in total sensitivity justifies the substantial effort of conducting these MF, even when considering their relatively moderate costs.

Table 5 Component sensitivities and total annual surveillance sensitivity of the PAR surveillance system

PAR surveillance component sensitivities for:	Sensitivity %			Costs CHF (≈ EUR)
	5%ile	Median	95%ile	
- Clinical Surveillance by farmer (*SComSeCLIN*)	6.7	11.6	18.9	15.55
- Clinical Surveillance by PHS (*SComSeCLINPHS*)	10.1	16.9	26.3	200.80
- Active sampling of 10 animals (*SComSeAS*)	56.6	81.7	95.1	422.00
- MF, examination by PHS (*SComSeMF*)	24.3	38.6	53.7	120.80
- MF, telephone check (*SComSeMFPHS*)	11.3	19.4	30.3	83.05
Total annual surveillance sensitivity PAR ($ToSe_{PAR}$)	95.1	99.4	99.9	842.20

For monitored fattening groups (MF) (*SComSeMFPHS*) and active sampling (*SComSeAS*), the component sensitivity is given for one MF and one visit, respectively, whereas costs are summed up over all MFand visits with active sampling in one year. (No extra value in EUR given due to marginal difference to CHF at the time of publication (07.05.2015: 1.037 CHF = 1 EUR); PAR = progressive atrophic rhinitis)

Finally, results indicated a very low component sensitivity of clinical surveillance for both diseases, be it by the farmer or the PHS veterinarian. Both diseases typically cause apparent clinical signs rather in older growing pigs (fattening pigs) than in sows and young piglets, the types of animals present in these multiplier herds. In sow herds they typically take a rather chronic and slowly progressing clinical course often without very typical symptoms, thus making it difficult to detect them via clinical examination only [6, 7].

Although the overall surveillance sensitivities are viewed as high, they represent summary measures over

one year. For a full picture of the effectiveness of the surveillance it is also necessary to know about the time it would take until an infection is detected. A PAR infection would be detected between 1.8 and 4.4 months after their introduction into the herd; the time a SD infection would go unnoticed would be slightly longer (between 2.4 and 6.4 months). Even though these estimates suggest a fast detection in the best case, in the worst case several months would pass until an infection is detected. Whether this is early enough to prevent negative consequences and further spread, strongly depends on the herd type and its trade patterns. It can be doubted though for the examined farm type of a multiplier herd that is situated at the top of the production pyramid and thus typically has frequent contacts to subsequent production units (herds supplied with the produced breeding piglets or gilts). The potential consequences of such an event were illustrated in an outbreak of PAR in a closed multiplier herd in 2011 [8]. Although the length of the period of infection in this herd could not be determined (at that time only one active sampling per year was conducted), within the tracing period from January 2010 to August 2011 overall 43 breeding herds had once or several times bought animals from that farm, of which 19 contracted the infection. These farms had to follow a rigorous depopulation-repopulation scheme according to the PHS guideline [5] and all other contact herds had to undergo intensive and repeated herd examinations over several months and faced trade restrictions until final proof of freedom from PAR. This shows that despite the lack of a generalized empirical value on what is *early enough*, for the examined farm type it should be attempted to detect the infection as early as possible. Although it cannot be quantified how much less severe the consequences would have been with the current surveillance scheme (or even better variants in terms of TD), this demonstrates that an efficient but costly surveillance is still justified since the costs of an outbreak – even if difficult to measure—by far outweigh those of surveillance.

Of course, all these results have to be interpreted with caution since the scenario tree models, like all models, are based on several assumptions regarding their structure and data. Several input parameters were subject to uncertainty, especially those that were based solely on expert opinions. Examples are the low estimated probabilities that symptoms were present during MF and that a farmer would notice and notify them, which considerably contributed to the resulting low component sensitivity of MF. Hereby it cannot be excluded that estimates were influenced by individual levels of experience and knowledge of the experts. These issues were sought to be alleviated firstly by founding the parameter estimates used in the models on a broad basis by addressing the questionnaire to all experts in the field available throughout the whole country (with a satisfactory response rate). Secondly, the principle of stochasticity, i.e. the use of probability distributions instead of point estimates, was applied. This was also done for test characteristics like the PAR test-specificity, where slightly lower values than the 100 % indicated by the laboratory were used as a precaution. For the future, further research will be necessary to fill these data gaps and substantiate the assumptions made in order to increase the certainty of the estimates. Furthermore, the time to detection can only serve as a rough estimate since it was based on a strongly simplified calculation: it was assumed that all events took place evenly distributed over the year, i.e. at equal intervals, which in reality is rarely the case. Additionally, the clinical surveillance by the farmer could not be considered in the calculation, because this event actually takes place every day. Moreover, for simplicity, best as well as worst case scenarios were based on median component sensitivity estimates. Finally, some farm individual characteristics that might have an impact on the actual sensitivity of the surveillance, such as farm size, biosecurity etc., were not addressed to keep the models as parsimonial as possible.

Finally, overall costs of the surveillance are certainly higher than calculated in this work, as we only focused on costs incurring to the PHS as an additional criterion besides surveillance sensitivity and time to detection to base their decisions on. Thus, we did not account for costs incurring e.g. to the farmer (labour costs etc.). Likewise we refrained from formally relating these costs of surveillance to benefits other than sensitivity and time to detection, although they would clearly have to be considered if a broader economic analysis (e.g. benefit-costs-analysis) was undertaken. The necessity of one or the other form of surveillance (including possibly considerable costs) is justified by the benefits for the farmers, i.e. confidence in the health status of their animals. This is especially important since the Swiss market structure demands for standardized health guarantees: it is extremely difficult to sell animals (be it breeding or fattening pigs) not meeting these standards, and farmers have to accept lower prices; some of the big retailers even accept only pigs / pig products that have been certified (according to the PHS) throughout the whole production chain.

Despite the described limitations of the method, scenario tree modelling proved beneficial for assessing the performance of disease surveillance, with its greatest advantages being its simplicity and flexibility. With this method, it was possible to gain one overall summary measure for the evaluation of a complex surveillance system. The method in general can be used for a broad

range of applications: its suitability at country or regional level was already demonstrated e.g. for freedom from avian influenza in Canada [13], classical swine fever in the European Union [14], or porcine reproductive and respiratory syndrome virus in Sweden [15]. The present work now gives proof of its successful application at herd level. Not only did the scenario tree models provide a good and realistic valuation of the current PHS surveillance system in multiplier herds as a whole and its constituting components. The adaptability of the models allowed an effortless adjustment to different alternative surveillance scenarios. The resulting outcomes gave valuable hints to the PHS on how to further improve its surveillance by optimizing sensitivity, time to detection and costs as the main criteria for decisions. The most obvious conclusion that can be drawn is that the focus should be laid on active sampling. This becomes especially clear when comparing the total surveillance sensitivity of our primarily investigated closed multiplier herds with the much lower sensitivity for multiplier herds with outsourced rearing of breeding gilts (61 % for SD and 81 % for PAR). The only difference in surveillance between the two herd types is that in the latter no active sampling is carried out. In contrast, omitting MF merely had any noticeable impact on the total sensitivities (and the worst-case time to detection would even decrease for SD due to the very low component sensitivities for MF). Considering this low contribution of MF to the total surveillance sensitivity, our suggestion would be to omit them and reallocate financial resources to an intensified active sampling. In accordance to the finding that the number of examined animals played an important role in the overall outcome, the most favourable scenarios comprised an increased number of animals sampled per visit. For SD, with twice ten pigs sampled per year, total sensitivity as well as time to detection would improve (99.6 %; 3.2 months on average) at only slightly higher costs (increase by 56 CHF (≈ EUR) to 1078.35 CHF (≈ EUR) per year). For PAR where the costs per laboratory test are much lower than for SD, the number of animals could be increased to 16 twice a year with keeping the same time to detection, slightly increasing the total sensitivity to 99.7 % and even reducing total annual costs by 84.00 CHF (≈ EUR) to 758.35 CHF (≈ EUR). In contrast, results indicated that for both diseases an increase in the frequency of visits for active sampling (4 visits with 6 animals sampled) would not bring any additional advantage considering the fairly higher costs. Finally, minor improvements could be achieved by increasing the disease awareness by the farmer, which was not deemed too high by the experts but had a rather low impact on the overall outcome. For the future, further substantial advancement of the surveillance would be conceivable with the employment of more accurate laboratory tests, especially for SD where sensitivity and specificity of the current method are only moderate [16]. Following discussion of the presented results with decision makers of the PHS, it was decided to modify the surveillance scheme accordingly, thus in the future omitting MF and intensifying active sampling.

To finish, scenario tree models like the ones presented herein can be valuable tools for national pig health services and other institutions conducting disease surveillance to assess the overall performance of complex surveillance systems at herd level. The versatility of the models allows their easy modification and adjustment to all kinds of surveillance components and scenarios. With little effort they can be adapted to other diseases under surveillance.

Conclusions

The present study revealed a generally satisfactory surveillance for both progressive atrophic rhinitis and swine dysentery in terms of their sensitivity to detect an infection in a herd. Identified weak points were the potentially long time to detection of an infection in a herd and the suboptimal use of resources, considering the poor sensitivity of monitored fattening groups for both diseases compared to their costs. It became clear that active sampling was the key component for effective surveillance of swine dysentery and progressive atrophic rhinitis. In order to optimize efficiency of the surveillance system, financial resources should be concentrated on an intensified active sampling at the cost of MF that should be abandoned. The methodology of scenario tree modelling proved to be a useful tool to assess the efficiency of surveillance at herd level.

Additional files

Additional file 1: Sensitivity tornado with relative impact of all parameters on SD surveillance sensitivity. This tornado graph indicates the relative impact of all parameters on the total sensitivity of SD (swine dysentery) surveillance. The larger the bar, the larger is the influence of the respective parameter at its current distribution (from 1st to 99th percentile) on the total SD surveillance sensitivity. (*CS* = probability of clinical signs in one or more animals in an infected closed multiplier herd; *FcV* = probability that a closed multiplier farmer informs vet./PHS about clinical signs, *VcS* = probability that veterinarian takes samples for laboratory examination, *Intrapr* = intra-herd prevalence (herd with clinical signs), *Intraprnoc* = intra-herd prevalence (no clinical signs), *TsensPCR* = probability that test classifies a true positive sample as positive (PCR after culture), *TspecPCR* = probability that test classifies a true negative sample as negative (PCR after culture), *CSMF* = probability that pigs show clinical signs during MF with infected animals, *MFFiV* = probability that MF farmer informs PHS about signs, *AnAS* = number of animals sampled via active sampling (per visit), *NAS* = number of visits with active sampling, *NCLINPHS* = number of visits with clinical examination, NMF = number of MF with telephone check, *NMFPHS* = number of MF with on-farm examination, *AnSUS* = number of animals sampled in the case of suspicion).

Additional file 2: Sensitivity tornado with relative impact of all parameters on PAR surveillance sensitivity. This tornado graph indicates the relative impact of all parameters on the total sensitivity of PAR (progressive atrophic rhinitis) surveillance. The larger the bar, the larger is the influence of the respective parameter at its current distribution (from 1st to 99th percentile) on the total PAR surveillance sensitivity. (*CS* = probability of clinical signs in one or more animals in an infected closed multiplier herd; *FcV* = probability that a closed multiplier farmer informs vet./PHS about clinical signs, *VcS* = probability that veterinarian takes samples for laboratory examination, *Intrapr* = intra-herd prevalence (herd with clinical signs), *TsensPCR* = probability that test classifies a true positive sample as positive (PCR after culture), *TspecPCR* = probability that test classifies a true negative sample as negative (PCR after culture), *CSMF* = probability that pigs show clinical signs during MF with infected animals, *MFFiV* = probability that MF farmer informs PHS about signs, *AnAS* = number of animals sampled via active sampling (per visit), *NAS* = number of visits with active sampling, *NCLINPHS* = number of visits with clinical examination, NMF = number of MF with telephone check, *NMFPHS* = number of MF with on-farm examination, *AnSUS* = number of animals sampled in the case of suspicion).

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
CN was involved in the conception and design of the study and supervised the doctoral student throughout all stages of the study (data collection including drafting of a questionnaire, creation of the scenario tree models, calculation and analysis of the results, interpretation of the results); she has drafted this manuscript. AH carried out data collection, the creation of the models and calculation and analysis of results as part of her doctoral thesis; SR participated in the data collection (compiling all PHS associated data) and actively participated in the creation and refinement of the scenario tree models; WZ was responsible for the conception and design of the study and contributed to the coordination of the study; HN provided significant intellectual content for the creation and refinement of the scenario tree models and helped to draft the manuscript. GS was responsible for the conception and design of the study and co-supervised all stages of the study. All authors read and approved the final manuscript.

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